

# Use of A Modified Drying Medium To Prevent Discolouration of Radiata Pine Sapwood During Kiln Drying

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## ABSTRACT

Wood darkening and kiln brown stain (KBS) in kiln drying has caused significant economic loss to the wood processing industry which. Although extensive studies have been performed, feasible drying techniques have not yet been developed to economically produce bright, pale colour wood from commercial drying.

The current work research has been conducted to dry radiata pine sapwood in hot air and in modified oxygen-free drying medium, namely, gases A, B and C. Four sets of matched samples were dried at three different temperatures of 50, 70 and 90°C, one set in a tunnel dryer simulating commercial hot air drying and three sets in a newly designed stainless steel cylinder, which was placed in an oven, for tests using the three oxygen-free drying media.

The results show that no obvious KBS was detected near the surface of sample boards dried in all of the oxygen-free gases except for one run using gas B at 70°C. However, for hot air drying, the discolouration of wood could only be reduced by drying at the low temperature of 50°C. How kiln drying in air at or above 70°C induces surface darkening and KBS. These results indicate that using an alternative non-oxygen atmosphere to kiln dry wood could reduce surface discolouration and KBS.

**Keywords:** kiln brown stain, radiata pine sapwood, oxygen-free drying medium, bright pale colour

## INTRODUCTION

Discolouration of wood during kiln drying is a well-documented phenomenon and has caused significant economic loss to the wood processing industry. The wood discolouration includes two aspects: an overall darkening of the wood and dark brown stain near the surfaces. The latter one is also termed as kiln brown stain (KBS), 0.5 to 2 mm beneath the drying surface of wood. Maillard reactions have generally been accepted as the main cause of discolouration and staining of the wood. The Maillard reaction could involve thousands of individual non-enzymatic reactions of amino acids, peptides and protein with sugars (Tomasik, 1989) and result in formation of phenols, furans, nitrogen heterocyclic compounds and yellow and brown polymers, known as melanoidins (Theander *et al.*, 1993). In a particular situation, certain reactions occur depending on surrounding conditions (such as temperature) and available chemical composition of the system (water activity, pH and sulphur dioxide), (Cioroi, 1999). Knowing the causes and factors for the formation of KBS, many studies have been carried out to control KBS, such as compression-rolling of radiata pine prior to kilning (Kreber and Haslett, 1997), drying at low temperatures and high air velocity or high relative humidities in conjunction with medium kiln temperatures (Kreber *et al.*, 1998). All of these conditions have, to a certain extent, reduced the frequency and intensity of kiln brown stain but unfortunately they lengthen the drying time. Some chemical pre-treatment systems have also been investigated in order to prevent KBS formation on the wood surface. For example in trials involving the use of two fumigants to treat freshly sawn radiata pine lumber and log sections, both fumigants reduced the severity of stain but the level of overall stain was still considered unacceptable (Kreber *et al.*, 1998). Therefore, practical drying technologies are yet to be developed which can both effectively prevent the KBS formation and be commercially feasible.

Although the exact causes of KBS are still not fully understood, it is believed that the oxidation of extractives and sap components contributes to the Maillard reactions and, consequently, to the stain development. Based on this observation and other important factors such as cost and environmental impact, this project has investigated the alternative technology of using an oxygen-free drying media, respectively, gas A, B and C to produce bright, pale coloured wood for drying of radiata pine sapwood. The results are compared with the wood dried using hot-air at commercial schedules.

## EXPERIMENTS

Experiments were performed in the Department of Chemical and Process Engineering, University of Canterbury. Matched radiata pine sapwood samples were dried using separately the three selected gases, in a newly designed cylinder at temperatures of 50, 70 and 90°C. Also, matched samples were prepared and dried using hot air in a tunnel dryer, also located in this department. In the tunnel drying, the drying temperatures were the same as those used with the alternative gases, and the air velocity above and beneath the test samples during the drying was 5m/s. After the drying tests were completed, the colour of the samples was evaluated using a digital spectrophotometer as described in McCurdy *et al.* (2005). Then the results of the alternative gas dried samples were compared with those of air-dried samples.

### *Sample preparation*

The boards used in the experiments were cut from two green boards which were collected from a local sawmill in Christchurch, New Zealand. The boards were cut from an approximately 25 year-old radiata pine log and the board lengths were 1.5m and 1.8m, respectively. After being collected from the sawmill, the two boards were cut immediately to prepare the samples.

From the 1.5 m long board, twenty-seven 50×40×120mm sample boards and thirty 50×40×20mm cross sections were prepared. Further thirty-three 50×40×120mm sample boards and thirty-six 50×40×20mm cross sections were cut out from the 1.8m board. All of the samples were flatsawn with the growth ring parallel to the flat surface (50 mm wide surface). The 50×40×120mm sample boards were used for the drying tests and the 50×40×20mm sections were used for determination of initial moisture content and density.

After cutting, all of the sample boards used for the drying tests were painted on the ends and sides with Devshield 216 thus drying occurred only on the flat surfaces in the tests. After sealing, the samples for drying were placed in a fridge at 5°C until required.

### *Drying using three oxygen-free gasses*

The set-up of the experiment instrument is shown in Figure 1. In the experiment, a stainless steel, enclosed cylinder of 60mm in internal diameter and 200 mm in height was placed in an oven which temperature could be controlled at 50 to 120°C. The empty cylinder was firstly

placed in the oven and preheated to the set point required. Then the wood sample board was placed inside the preheated cylinder. Before drying the cylinder was purged by running the gas through. In the drying, the gas flux was controlled by the valve at the exhaust end in a way so that the evaporated steam was carried away by the gas but heat loss was minimised. Regulators were mounted at the top of the gas bottle to ensure that the drying cylinder was not over-pressurised. Drying temperatures of 50°C, 70°C and 90 °C were used for each gas..

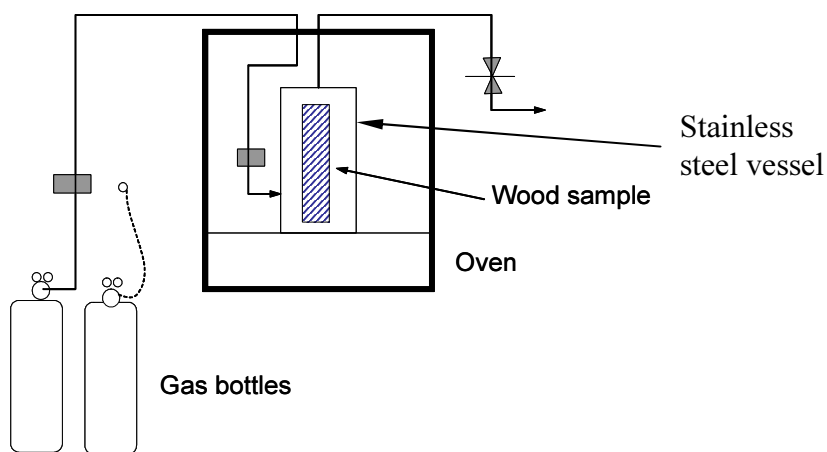


Figure.1. Experimental setup for oxygen-free gas drying.

The drying was stopped when the final moisture content reached about 12%. Actual final moisture contents varied from 10 to 20%.

#### *Drying in a tunnel dryer using hot air*

Matched samples were also dried in a tunnel dryer which was controlled by a PC running Advantech® Genie™ data acquisition and control software. This package controlled drying temperature and humidity of the air, as well as the air velocity. It also recorded data from the mass balance as well as temperature and humidity readings. The three single step drying schedules :(dry-bulb/wet-bulb temperature) of 50/40°C, 70/50°C and 90/60°C used for the tunnel drying tests are used in commercial drying.

#### *Sample slicing and colour measurement*

After drying, a 25×25×50 mm cross section was cut from the mid-length and mid-width position of each sample. The section covered the full thickness thus the 25×25 mm surfaces were part of the board flat surfaces. Each block was sliced into less than 1 mm thick layers using a special designed machine. The first ten slices, taken from the exposed board surface, were recorded and kept in a plastic bag. Finally, the colour of the ten slices from each sample section were measured using a Minolta 2500d handheld reflectance spectrophotometer. The colour data were represented using the CIELAB L\*a\*b\* colour space and stored in the computer for further analysis. However, the most relevant colour indicator for KBS is the brightness and therefore, in this paper, only brightness (L\*) is discussed.

## RESULTS AND DISCUSSION

Table 1 shows the average lightness values (L\*) for all the samples used in the experiments. The average lightness is the mean value averaged over all of the ten slices, core lightness is the mean value for slices 4-10 and surface lightness is the mean value for slices 1-3. Surface darkening is the percentage difference between the surface and the core. In commercial practice, the actual KBS occurs at 0.5-2 mm layer beneath the drying surface. Considering that the slices were very thin (less than 1 mm) and the wood surface was rough for the sawn timber, average colour values over the surface three slices is more consistent to reflect the difference between treatments. However, the actual colour profile along the thickness can be found from the plots in Figures 2-5.

TABLE 1: Colour variation of the thickness slices for each gas and drying temperature

Gas	DB (°C)	Ave. <sup>a</sup>	Core <sup>b</sup>	Surf <sup>c</sup>	Surf. <sup>d</sup> change(%)
A	50	80.8	81.7	78.7	3.7
	70	80.3	80.9	78.9	2.5
	90	80.6	81.3	79.1	2.7
B	50	80.2	80.9	78.8	2.6
	70	80.1	82.9	73.6	11.2
	90	78.7	79.6	76.6	3.8
C	50	79.0	80.4	75.8	5.8

	70	79.3	80.3	76.9	4.3
	90	77.6	80.2	71.6	10.7
Air	50/40	81.6	83.5	77.1	7.7
	70/50	79.9	80.9	77.4	4.4
	90/60	78.9	81.9	72.2	11.9

a: Average brightness; b: Core wood brightness; c: Surface wood brightness; d: Surface brightness change (difference between the core and then surface)

Table 1 shows that the average brightness of the boards dried in gases A and B (except for the 70°C run) had higher values of lightness thus the wood was brighter on average. These values are similar to those for the boards dried at low temperature using air. However, boards dried using gas C were slightly darker than the samples dried in gases A and B.

In terms of surface darkening, of the three gasses tested, gas A was the best one as all of the boards had the highest surface lightness values thus the surface colour changes were the lowest. These results are superior than for all of the boards dried using hot air, at all drying schedules tested (as reported by McCurdy *et al.* 2003). Because the main reason of surface darkening is the formation of KBS, the severer darkening on the wood surface indicates the worse kiln brown stain developed. Selected results on colour profile and colour comparison are shown in Figs.2-5 for the sample boards dried in the four different gasses (gases A, B, C and air) at various temperatures (50°C, 70°C, 90 °C).

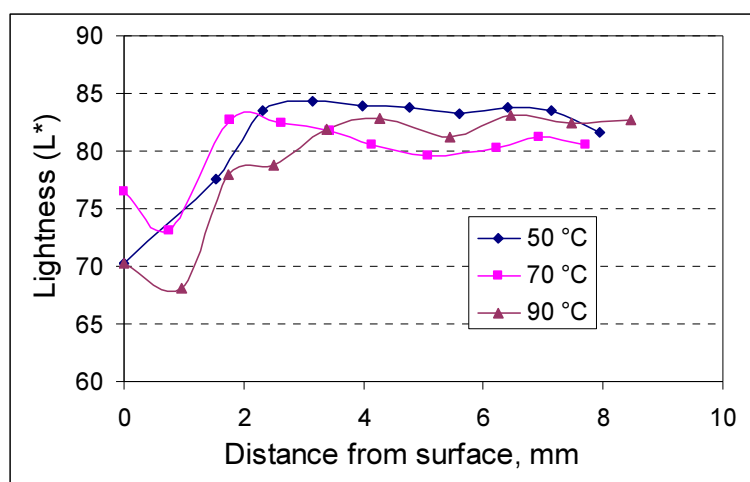


Figure 2. Colour profile for sample kiln dried in air.

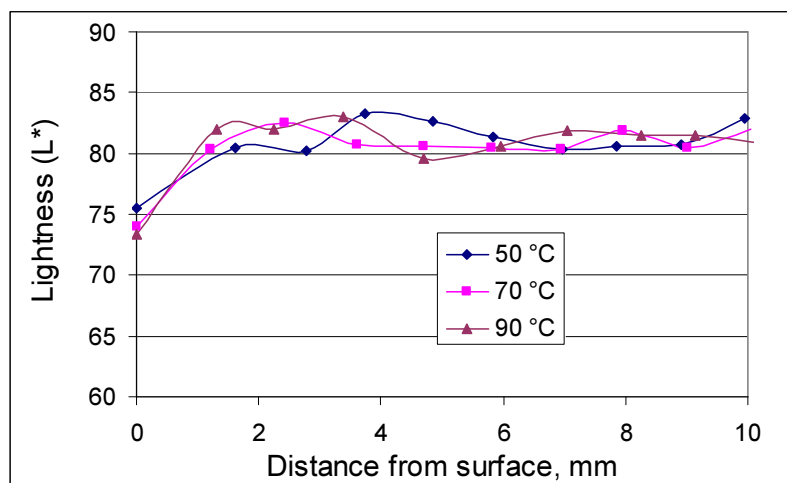


Figure 3. Colour profile for gas A dried sample.

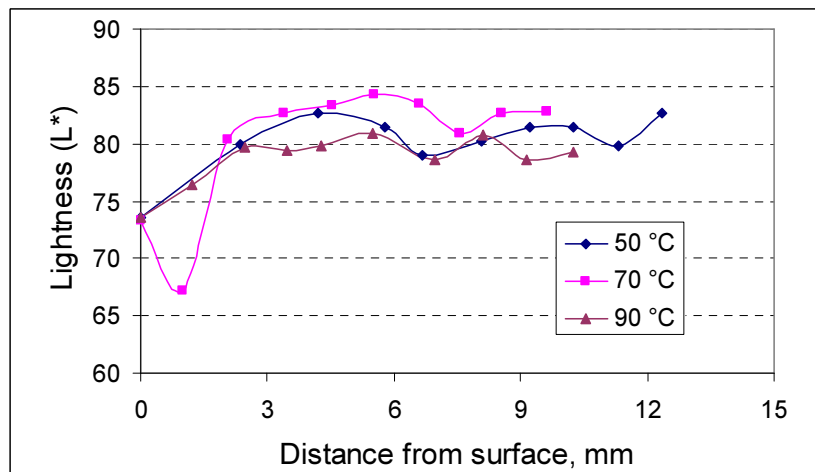


Figure 4. Colour profile for gas B dried sample.

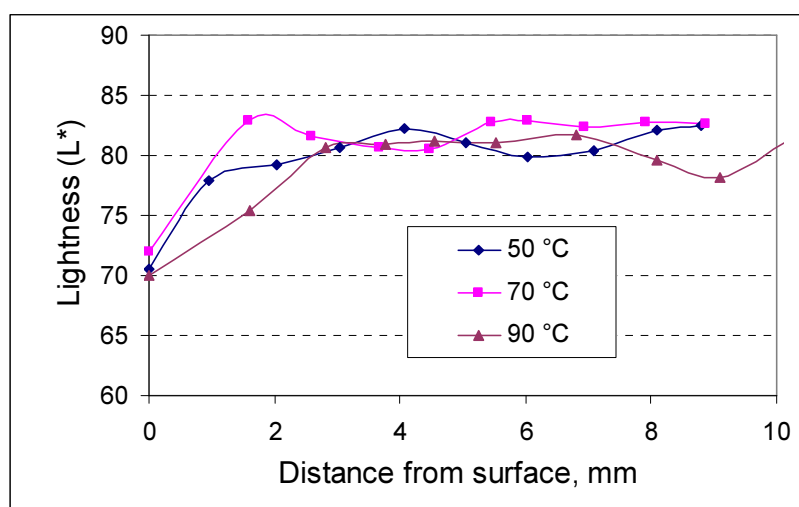


Figure 5. Colour profile for gas C dried sample.

KBS is a well-known chocolate brown discolouration that develops approximately 0.5 to 2 mm under the board surface during kiln drying, thus lightness profile from surface towards the core can be used to as the best indicator for the formation of KBS. From Fig.2, it was observed that with conventional hot air drying the KBS formed 1 mm beneath the surface at drying temperatures of 70 and 90°C, but KBS was reduced with low temperature drying at 50°C. However, use of the oxygen-free gases almost eliminated KBS the exception being one run (gas B at 70°C). This is illustrated by the absence of dark colour 1 mm beneath the drying surface. The general darkening right at the surface is believed to be the wood yellowing due to exposure to the atmosphere and light during preparation of the samples.

Among the three gases tested, there are some differences in terms of surface colour changes during drying. Gas A gave the brightest colour with the surface brightness (L\*) being around 75 and the wood brightness increasing towards the core. Gas B could give similar colour profile except for the drying at 70°C. The exact reason for this is not clear as it was expected the darkening should have occurred at higher temperature but drying at 90°C gave a brighter colour without apparent KBS. The wood dried using gas C was also lack of apparent KBS but the average colour near the surface was slightly darker than wood dried in gases A and B.

The most significant observation is that gas A can produce bright, pale colour with low surface darkening and low KBS even at a temperature of 90°C. This result could be of major interest to industry as they could be able to improve surface brightness and reduce KBS and yet still use the rapid drying 90°C to achieve optimum profits.



During the drying tests in the oxygen free media, the humidity was not measured and the flow rate was controlled by the exit valve by minimising the heat loss and preventing the condensation occurring. However, separate studies by McCurdy *et al.* (2003; 2005) have found that the relative humidity affects the wood colour and KBS mainly due to the drying time. Further studies will be performed in larger scale dryer and the effects of relative humidity will be investigated.

## CONCLUSION

Research has been conducted on the drying of radiata pine sapwood in hot air and alternative oxygen-free drying media using drying temperatures of 50, 70 and 90°C. To provide a comparison with current commercial drying matched samples were also dried in a tunnel dryer using these three drying temperature schedules. The results show that conventional kiln drying in air at or above 70°C induced apparent kiln brown stain (KBS) and surface darkening and only low temperature drying (50°C) could these discolorations be reduced. For the three oxygen-free gases tested, KBS was effectively eliminated, the exception being for one run using gas B at 70°C. The surface colour for all of the boards was darker than the core which is believed to be the wood yellowing during the sample preparation.

These results indicate that using a modified medium to dry the wood could be an effective way for preventing surface discolouration. With particular interests to industry is that by using gas A, drying temperature does not affect the surface colour and the KBS, thus the wood could be dried at a fast drying rate. A further study is currently being undertaken to validate the findings of this study and to investigate the economic feasibility using the oxygen-free gases within the dryer.

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